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SBIR Final Technical Report (unclassified)

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Leap-Ahead Air Filtration Innovations and Technologies (LAAFIT)
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Abstract

We are pleased to report the project has progressed to a point where we can begin to make clear predictions of future expectations. The results, although not completed in this phase, are in line with what we expected. Lab testing completed in this phase delivered results which fell short of the 99.5% efficiency SBIR goal. However, the test results correlated well with the CFD predictions. Near the end of this phase, we were able to apply what we learned to incorporate design improvements into our models. These models have been evaluated with CFD. The results are promising.

The trend in the analysis indicates that if our team is provided adequate development time and budget, the SBIR goal is attainable. Power consumption and unit cost of the latest models have not been extensively analyzed; however, preliminary evaluation would indicate that this technology may have commercial and military applications. Cost and power consumption, along with proving the performance will be the main focus of future phases of the program.

At this time, we are applying what we learned in this effort to improve our engine air precleaner offerings. The goal is to offer a version of the technology that will have commercial applications as well as provide our R&D department with the opportunity to continue the original work.

Note: Phase II funding would focus this effort towards the original topic. In the event that Phase II funding is not available, some work will continue but will be refocused to precleaner applications as outlined above.

Project Overview

As stated: the Phase I objective was to prove that it is possible to create an air filtration system, with a non-barrier filter, that is capable of achieving 99.5% efficiency, in the lab, with either a fine or coarse dust. The proposed solution is to consider size, weight and power consumption. The underling goal is create a system that can be of use to a vehicle of military significance.

The proposal and work that Sy-Klone has focused on during Phase I is to develop and optimize a version of our powered air cleaning system technology. Current offerings do not meet the efficiency nor the ultimate engine air flow ranges indicated in the topic.

The proposal that Sy-Klone is developing incorporates a high efficiency brushless DC motor which offers reliable power in a compact design. It also incorporates a computer optimized, ducted, fan similar to what might be found in a modern turbojet engine.

During this phase Sy-Klone has concentrated its in-house and contracted efforts on mathematical and computer modeling. Preliminary testing of significant milestone configurations of concept model-level prototypes has been done to support the theoretical predictions.

Sy-Klone's Phase I primary objectives were to prove that our solution has the ability to meet the stated requirements and to identify potential wheeled vehicles that have tactical or combat applications.

The specific Goals and objectives (Tasks) of phase I are summarized as follows:

1) Identify current and future applications
2) CAD design proposal and computer aided design analysis (FEA & CFD)
3) Analyze the size and weight of the complete design proposals
4) Analyze the power consumption requirements

5) Demonstrate proof-of-principal in the lab
6) Identification of any safety filter requirement
7) Report Technical Progress at the end of the program

Task 1: Identify current and future applications
Specific military vehicles such as the HMMWV and the HEMTT were identified as possible subject vehicles. However TACOM's interest in modifications to the air intake of these vehicles was minimal and it was not practical within the time available to pursue these. It was decided instead to target airflow ranges that would apply to current and future systems. The original plan was to target engines with airflow demands of 650 CFM and below. This range was selected because it includes the air flow requirements of the HMMWV, as well as, many of the combat service and combat support vehicles such as, heavy equipment, used by the U.S. Military. We have also begun work directly with the commercial original equipment manufacturers that supply these vehicles and equipment to the U.S. Military.
For the purposes of this SBIR topic, we consider this task closed, however the identification of commercial applications will continue to be a major Sy-Klone focus in the immediate and foreseeable future.

Task 2: CAD design proposal and computer aided design analysis (FEA & CFD)
In all interim reports, this was identified as an ongoing task. This task, in conjunction with the lab analysis identified in task 5, was the primary focus of the work done at Sy-Klone. The objective of the work in Phase I was to provide evidence that the identified goal of the 99.5% efficiency is attainable. The final design, tooling, building and testing of the production intent unit are scheduled to be completed during Phase II.

To date, three iterations of the separating chamber and several iterations of the fan speeds, and air flow rates have been evaluated. Computer aided projections of separation efficiencies are improving and nearing the stated goal. The following figures 1 through 12 (summarized in the following chart (fig 13) indicate only the significant milestone iterations of our powered air filtration system. Many additional evaluations have been done in addition to milestones which are highlighted below but are not pertinent to this report. The importance of this section is that these major milestone iterations were evaluated with CFD and the results were compared to lab data collected on prototype models which were also tested. Lab results consistently exceeded the CFD evaluations.

Generation 1

The computational fluid dynamics analysis shown in Figure 2 was derived using the first generation model shown in Figure 1. The following boundary conditions were applied to the model. The impeller was given a constant rotation velocity of 7000 rev/min. The inlet boundary and ejection ports boundary surfaces were both given a zero pressure boundary. The outlet was given a volumetric flow rate of 100 ft^3/min on the outlet surface boundary with a velocity vector exiting the precleaning device. The particle trace analysis was derived using a 10 x 10 radial particle trace pattern. (**Note:** This refers to 10 rows of particles, each containing 10 virtual particles, for a total of 100 particles, distributed as shown in Figures 3, 7 & 11). The particle trace analysis shown in Figure 4 resulted with 10 particles passing to the outlet surface boundary. It is concluded from this analysis that this model has a computational efficiency of 90 percent.

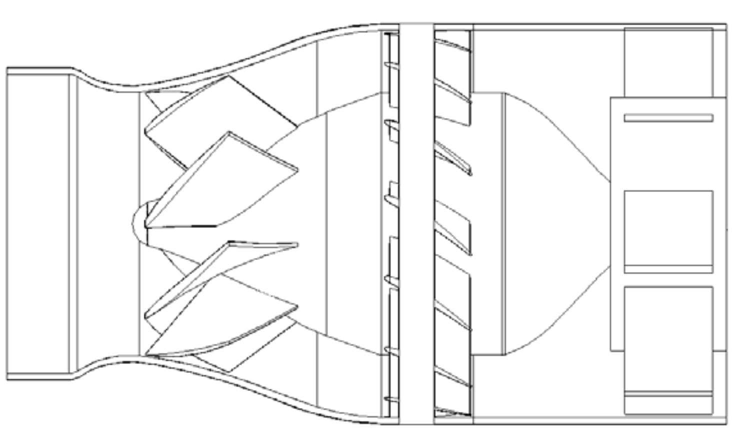

Figure 1: First Generation Solid Edge Model

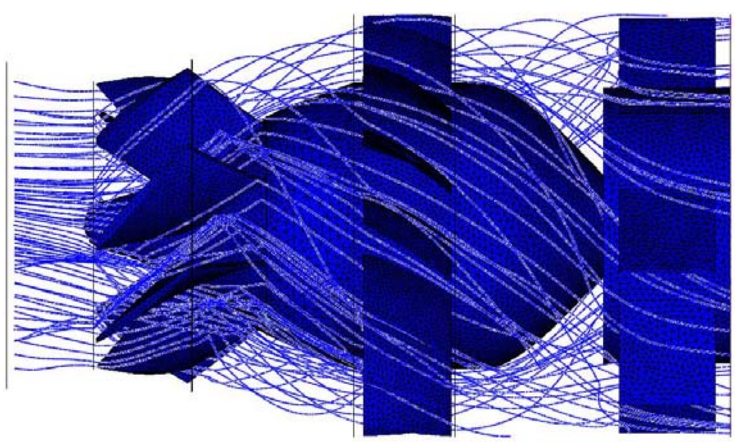

Figure 2: First Generation Particle Trace Analysis

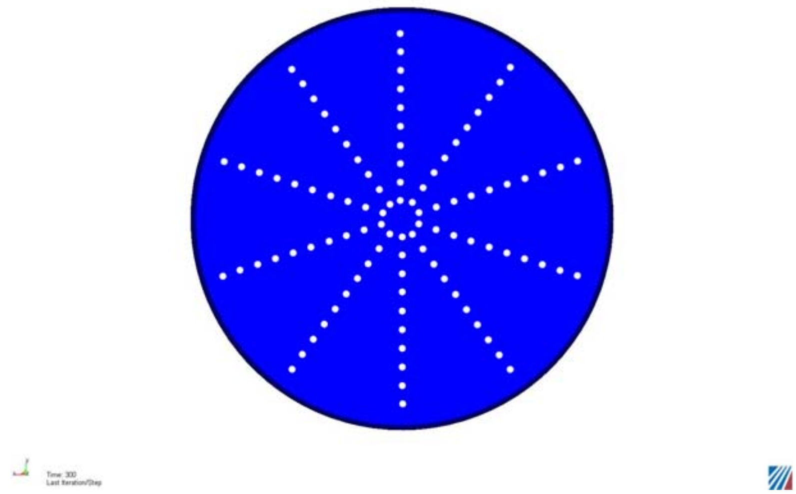

Figure 3: 10 x 10 Radial Particle Trace Pattern

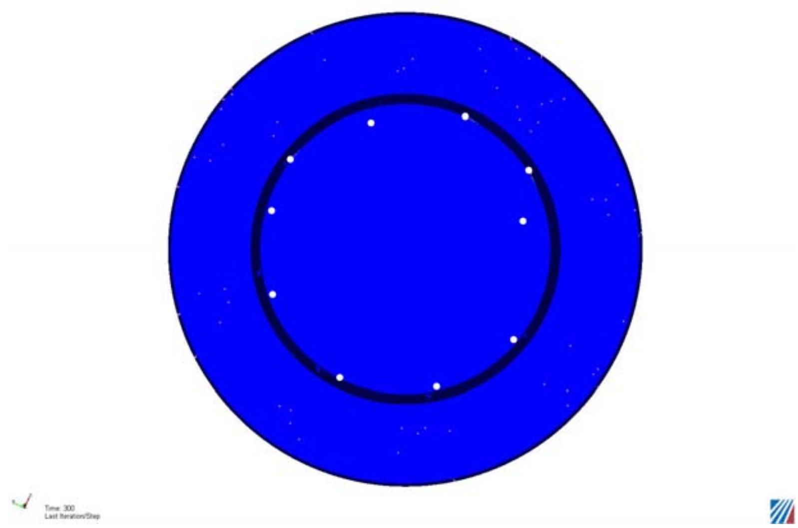

Figure 4: Outlet Surface Boundary Particle Trace Results
10/100 – 90% Precleaner

Generation 2

The computational fluid dynamics analysis shown in Figure 6 was derived using the second generation model shown in Figure 5. The model was improved over the prior generation by adding additional width to the separation chamber. The following boundary conditions were applied to the model. The impeller was given a constant rotation velocity of 7000 rev/min. The inlet boundary and ejection ports boundary surfaces were both given a zero pressure boundary. The outlet was given a volumetric flow rate of 100 ft^3/min on the outlet surface boundary with a velocity vector exiting the precleaning device. The particle trace analysis was derived using a 10 x 10 radial particle trace pattern as shown in Figure 7. The particle trace analysis shown in Figure 8 resulted with 8 particles passing to the outlet surface boundary. It is concluded from this analysis that this model has a computational efficiency of 92 percent.

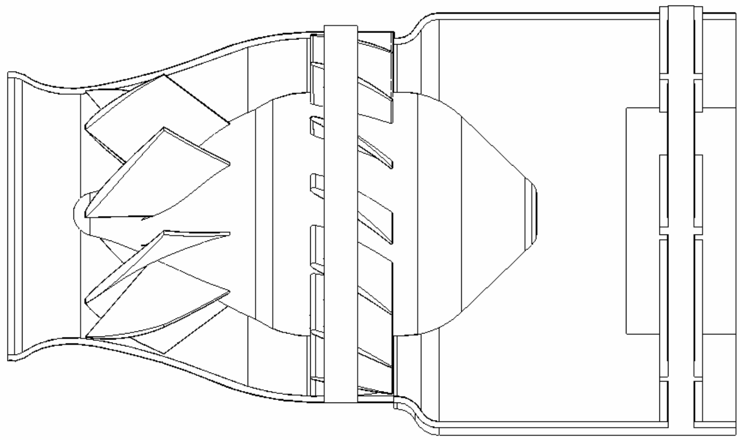

Figure 5: Second Generation Solid Edge Model

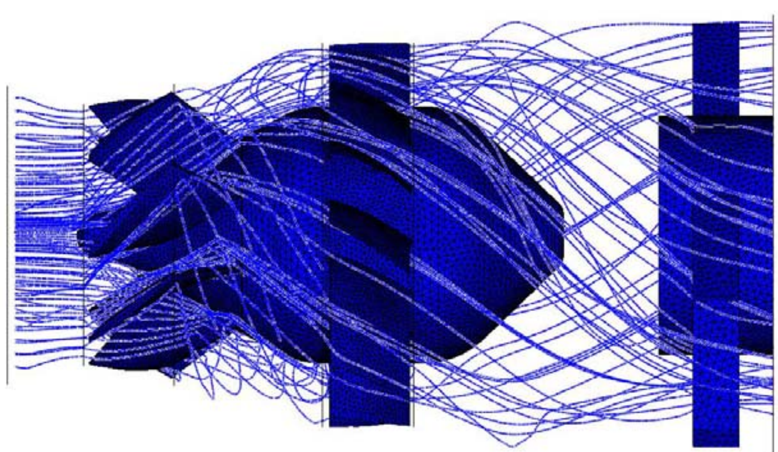

Figure 6: Second Generation Particle Trace Analysis

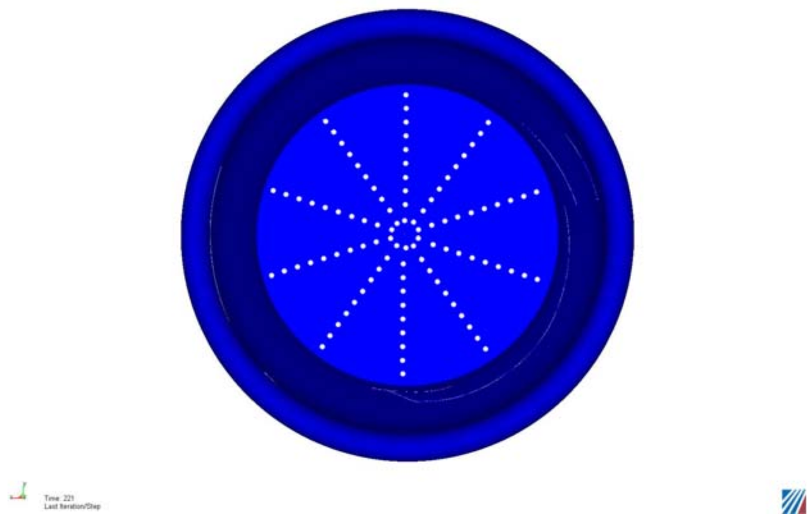

Figure 7: 10 x 10 Radial Particle Trace Pattern

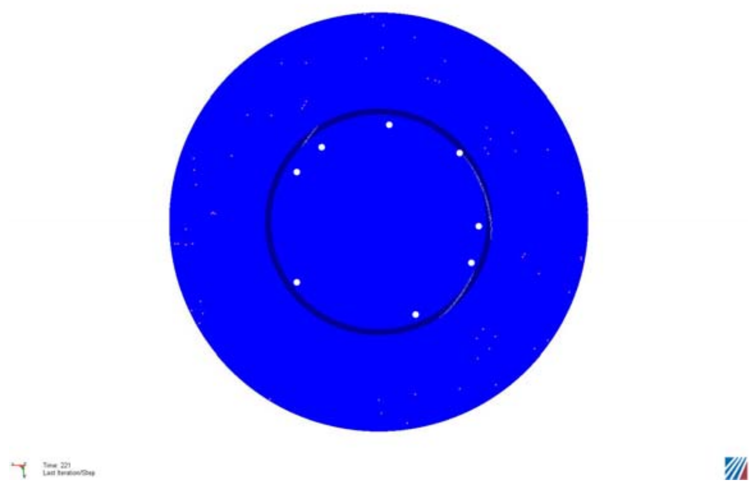

Figure 8: Outlet Surface Boundary Particle Trace Results
8/100 – 92% Precleaner

Generation 3

The computational fluid dynamics analysis shown in Figure 10 was derived using the third generation model shown in Figure 9. The model was improved over the prior generation by first increasing the length and width of the separation chamber. Flow directors were also added to aid the migration of the debris particles to the outer walls of the precleaning device. The following boundary conditions were applied to the model. The impeller was given a constant rotation velocity of 7000 rev/min. The inlet boundary and ejection ports boundary surfaces were both given a zero pressure boundary. The outlet was given a volumetric flow rate of 100 ft^3/min on the outlet surface boundary with a velocity vector exiting the precleaning device. The particle trace analysis was derived using a 10 x 10 radial particle trace pattern as shown in Figure 11. The particle trace analysis shown in Figure 12 resulted with 3 particles passing to the outlet surface boundary. It is concluded from this analysis that this model has a computational efficiency of 97 percent.

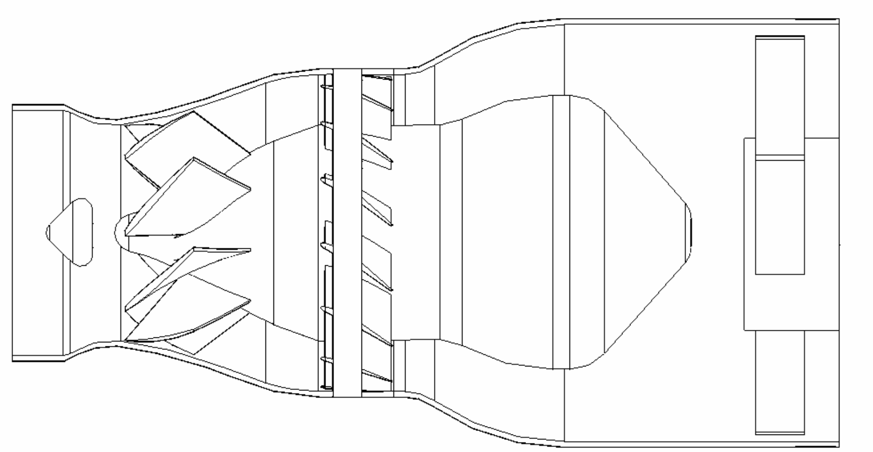

Figure 9: Third Generation Solid Edge Model

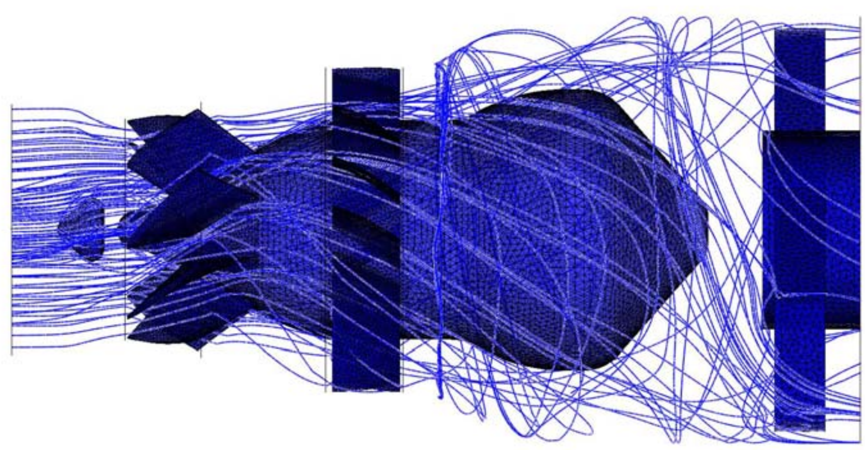

Figure 10: Third Generation Particle Trace Analysis

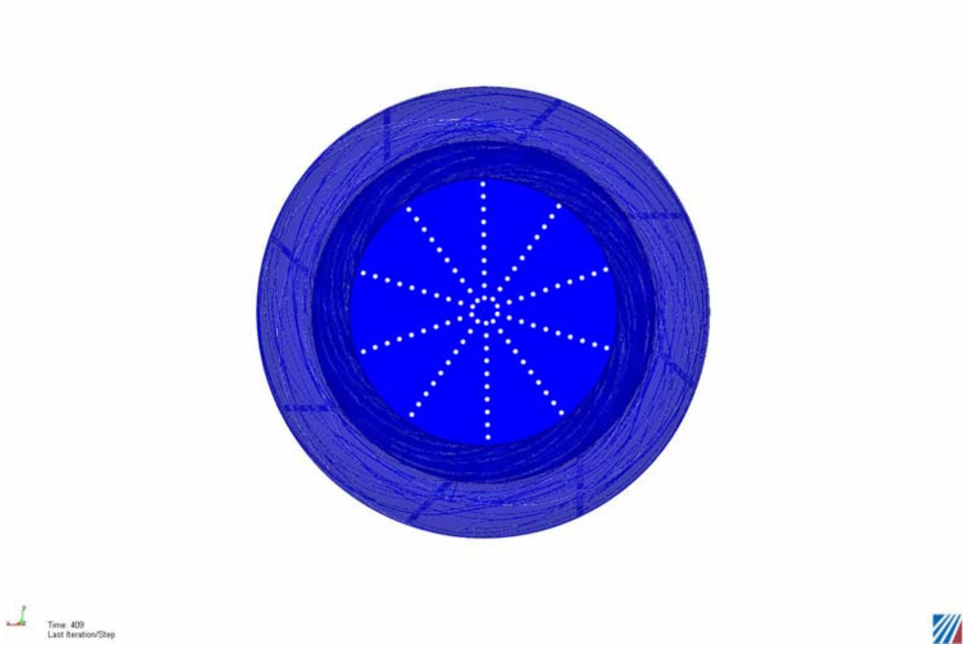

Figure 11: 10 x 10 Radial Particle Trace Pattern

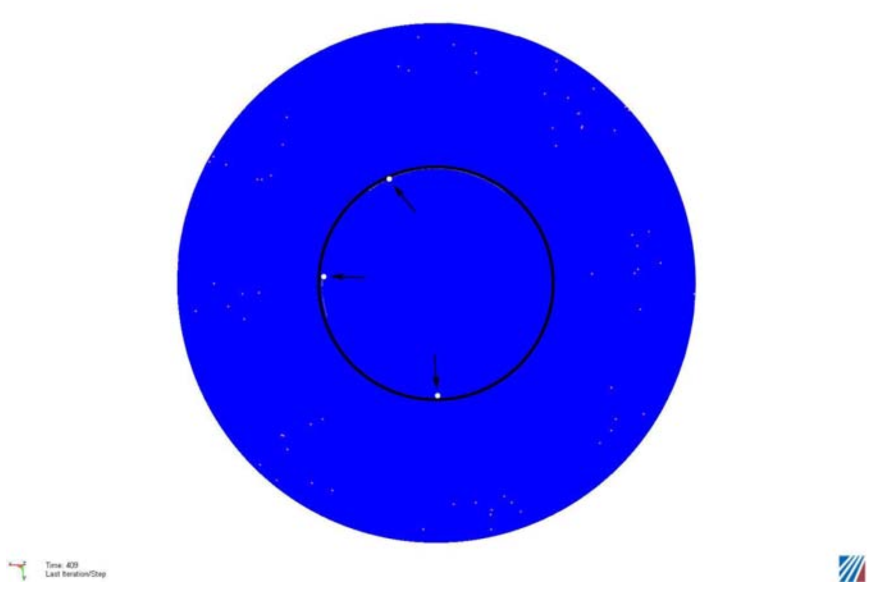

Figure 12: Outlet Surface Boundary Particle Trace Results
3/100 – 97% Precleaner

Summary of CFD analysis efficiency projections

DESIGN GENERATION	DESCRIPTION	**CFD** EFFICIENCY PROJECTIONS
Milestone #1 (Generation 1)	* Short Separation chamber, * Standard ejection OD	90%
Milestone #2 (Generation 2)	* Short Separation chamber, * Increased ejection OD	92%
Milestone #3 (Generation 3)	* Increased separation Chamber Length * Flared Ejection Chamber OD * Inlet and Separation chamber flow directors	97%

Figure 13: CFD Summary

Task 3: Analyze the size and weight of the complete design proposals

The size of the most current iteration is shown in the illustration below (fig 14). The predicted weight is less than 20 pounds. The weight and size of this device were based on internal specifications created as a starting point for evaluation. These figures were generated as an attempt to design the solution in a size envelope that will potentially fit the space available in current applications.

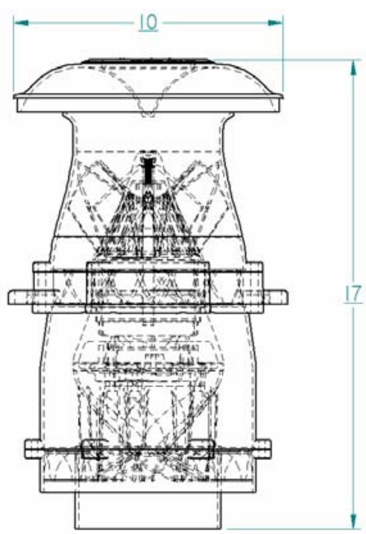

Figure 14: Targeted basic size and shape

For the purposes of this SBIR topic, we consider this task closed. However, this will be an on-going task and concern as Phase II and/or Sy-Klone targeted efforts identify different applications.

Task 4: Analyze the power consumption requirements
For the purposes of this study, we have targeted 24 VDC systems (running at 28 VDC) and have limited the power consumption to 700 watts. This target was incorporated into the original CFD design analysis and confirmed during preliminary lab testing.

For the purposes of this SBIR topic, we consider this task closed. However, some of our models indicate that higher separation efficiency may require more power. This will also be true in higher engine air volume (CFM) applications. As indicated, the technology being developed at Sy-Klone incorporates an electric powered, particle separation chamber. To meet the defined efficiency goal additional power may be required. This indicates that the specified goal of 700 watts may not be practical for all applications.

Task 5: Demonstrate proof-of-principal in the lab
To date, two rapid prototypes incorporating the design solutions developed in Task 2 have been evaluated. These tests were conducted in accordance with ISO 5011 and Sy-Klone test procedures. (See test set up fig 15 below). The results are promising. As expected there are significant differences between the CFD projections and the results of tests performed in the lab. As shown in Task 2, CFD analysis of the original design indicated that the efficiencies would be around 90%. The chart below shows that a rapid prototype of this milestone iteration tested above 91% gravimetric efficiency.

The data and graph below illustrate that the work done by Sy-Klone is yielding continual improvement and trends toward the original SBIR goal of 99.5% efficiency. The data (Fig 16 below) indicates that the most recent rapid prototype is approaching 93% in lab tests. It is important to point out that even though the lab tests of relatively low-tech, rapid prototypes fell short of the 99.5% efficiency target, the trends are very positive. It is also important to note that in every case, the results generated in lab tests exceeded the CFD projections by significant amounts.

Continuing development work has resulted in designs that incorporate features that were identified as having significant positive impact on results. CFD analysis of these most recent design iterations indicate that the separation efficiency increases. Assuming that the positive trend continues, and the lab results continue to exceed CFD projections, it is the opinion of this team that identified goal of 99.5% efficiency is attainable.

As of this final report, no additional Phase I rapid prototypes of the system are planned. The additional prototypes, necessary to establish the capability, not only to meet the 99.5% efficiency goal, but also to assure statistical compliance are scheduled as part of Phase II.

Note: The preliminary testing done at Sy-Klone was done at single CFM points per ISO 5011. It the intent that in Phase II all testing will be done at variable air flows in accordance with MIL-PRF-46736.

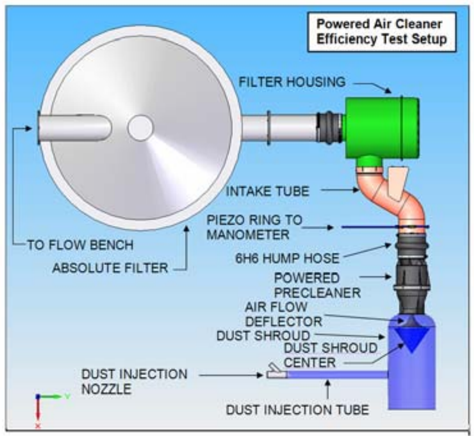

Figure 15: Basic Lab set up schematic

Comparison of efficiency projections to CFD analysis		
DESIGN GENERATION	**CFD** EFFICIENCY PROJECTIONS	PROTOTYPE EFFICIENCY DATA
Generation #1	90.0%	91.2%
Generation #2	92.0%	93.0%
Generation #3	97.0%	not tested

FIG 16 Lab Data vs. CFD Comparison

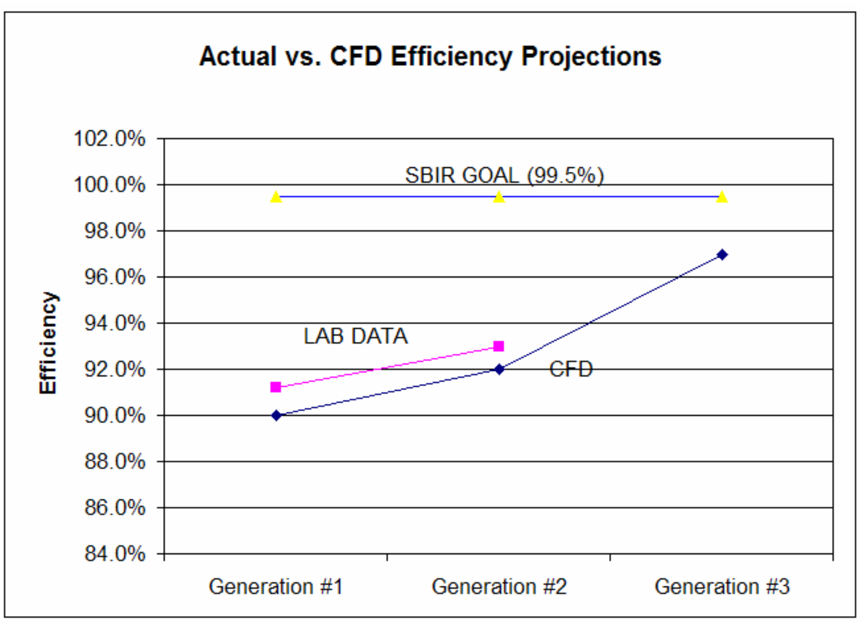

FIG 17 Lab Data vs. CFD Comparison

Task 6: Identification of any safety filter requirement
This task can only be completed after the work completed in task 5 confirms the concept and identifies the prediction of statistical variation. At this time, Sy-Klone recommends that any mechanical or electrical solution to this SBIR topic incorporate a safety filter that is designed, at a minimum, to protect the engine and provide some run time in the event of a catastrophic failure of the non-barrier air filtration system.

Conclusion

As indicated by the data, the lab testing completed in this phase delivered results which fell short of the 99.5% efficiency SBIR goal. However, the test results correlated well with the CFD predictions shown in Fig 17. In all cases, the Lab results exceeded the CFD predictions.

The projection of these demonstrated trends, in both the CFD and the analysis of the prototypes in the lab indicate that if our team is provided adequate development time and budget, the SBIR goal is attainable. Future focus will be on 3 factors that would lead to a commercially viable system:

Performance (meeting or exceeding the SBIR goals)
Power consumption
Unit cost

At this time, we are applying what we learned in this effort to improve our engine air precleaner offerings. The resultant direction, after completing phase I is to continue this work in this technology. Our team will continue to with the program with the current goals of: (1) offering a version of the technology that would have commercial applications as well as (2) provide our R&D department with the opportunity to continue the original work.
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